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Schemmann et al.

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(54) **AMPLIFIER COMPOSITE TRIPLE BEAT (CTB) REDUCTION BY PHASE FILTERING**

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(51) **Int. Cl.**
H03F 1/26 (2006.01)

(52) **U.S. Cl.** **330/149**; 330/310; 330/306

(58) **Field of Classification Search** .... 333/177, 333/28 R, 138–140; 330/165, 149, 310, 330/306; 725/127, 149

See application file for complete search history.

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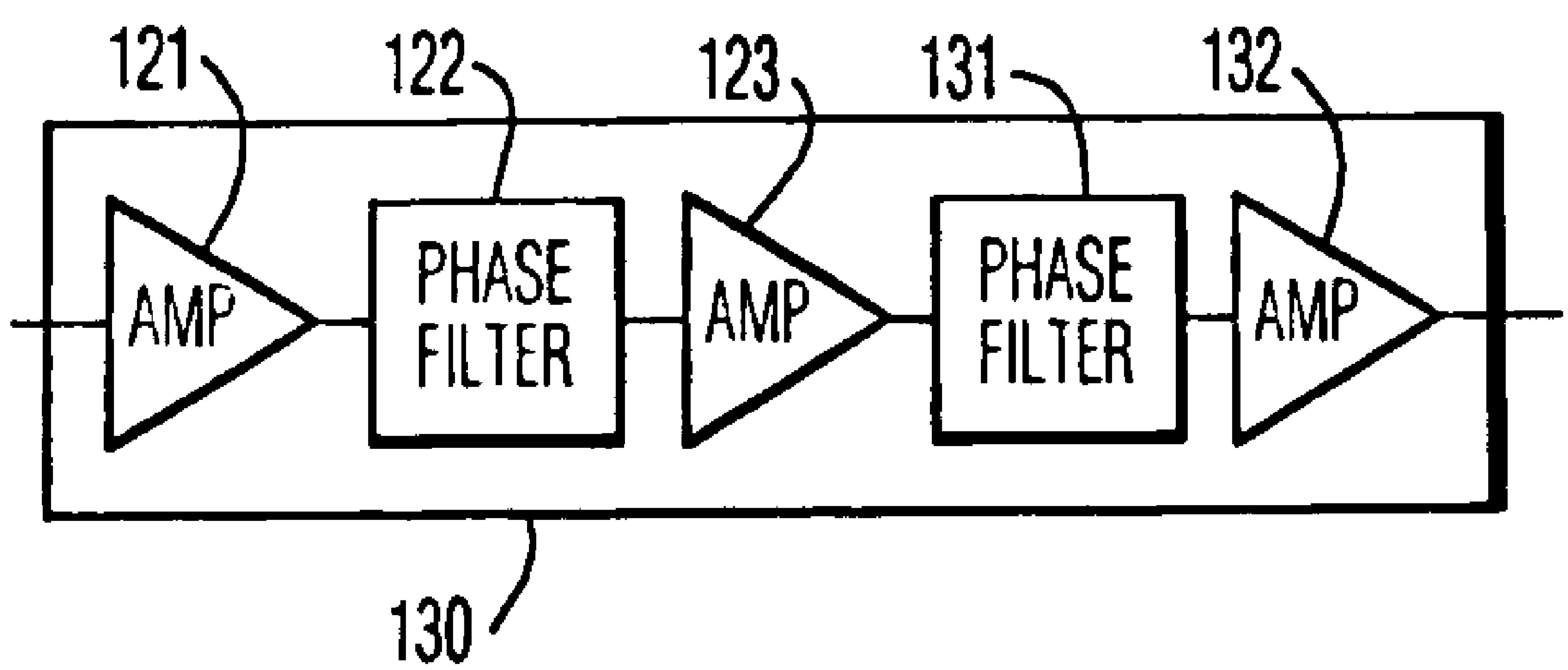
(74) *Attorney, Agent, or Firm*—FSP LLC

(57) **ABSTRACT**

In a broadband communication system there are multi-stage power amplifier systems for amplifying the power of radio-frequency (RF) communication signals. Each stage of the amplifier system results in composite triple beat (CTB) distortion, and if the phase of the CTB distortions are approximately the same (i.e. are in-phase), then the amplitudes of the distortions are added (i.e. "20 dB" rule). The amplifier system of the invention includes one or more phase filters positioned in series between the power amplifier stages. The phase filters are adapted to shift the phase of the communication signals, so that the phase of CTB distortions, resulting from the amplification of the communication signals in the amplifier stages between the phase filters, are substantially different (i.e. are out-of-phase). Thus, only the power of the CTB distortions are added (i.e. "10 dB" rule).

4 Claims, 7 Drawing Sheets



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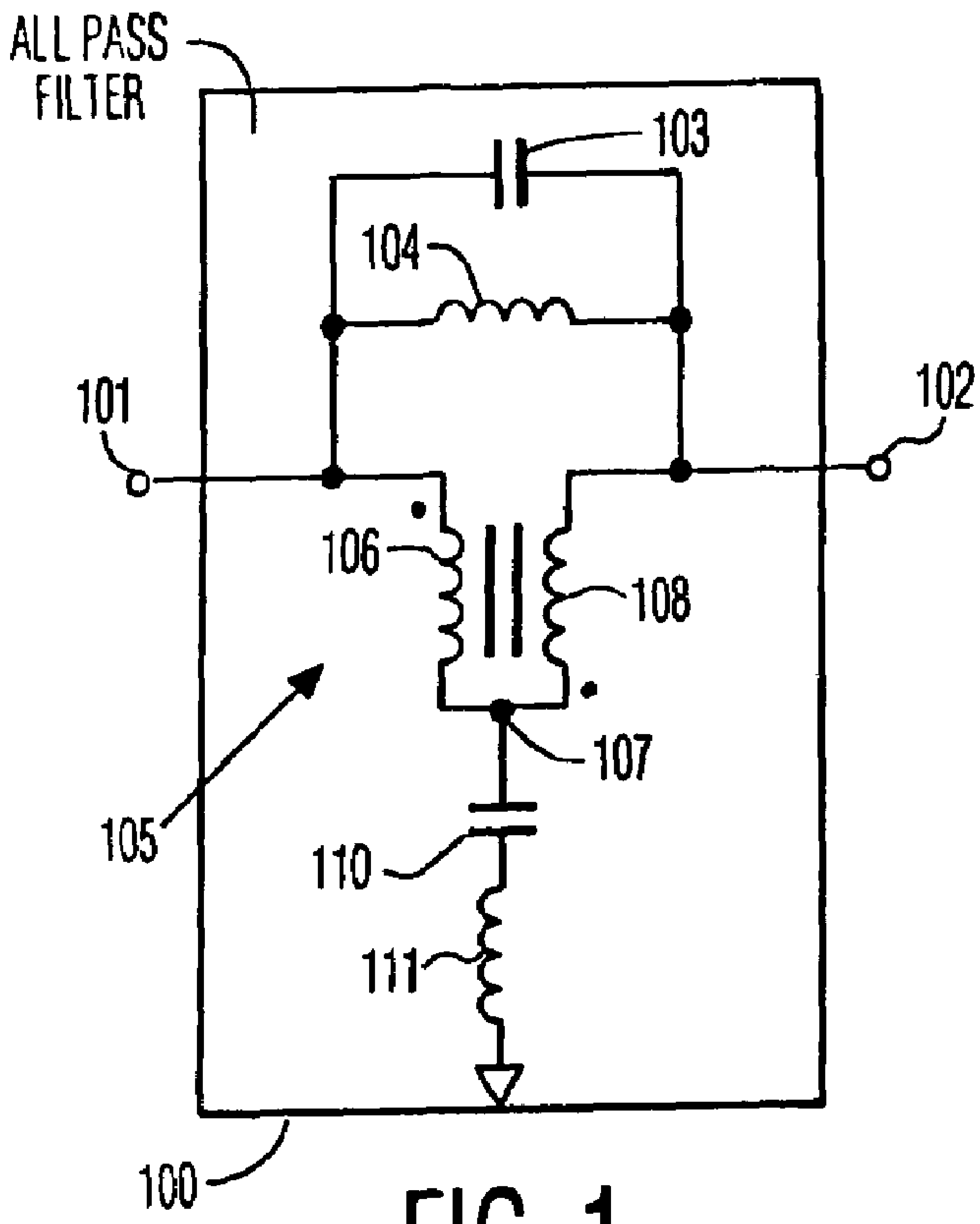


FIG. 1

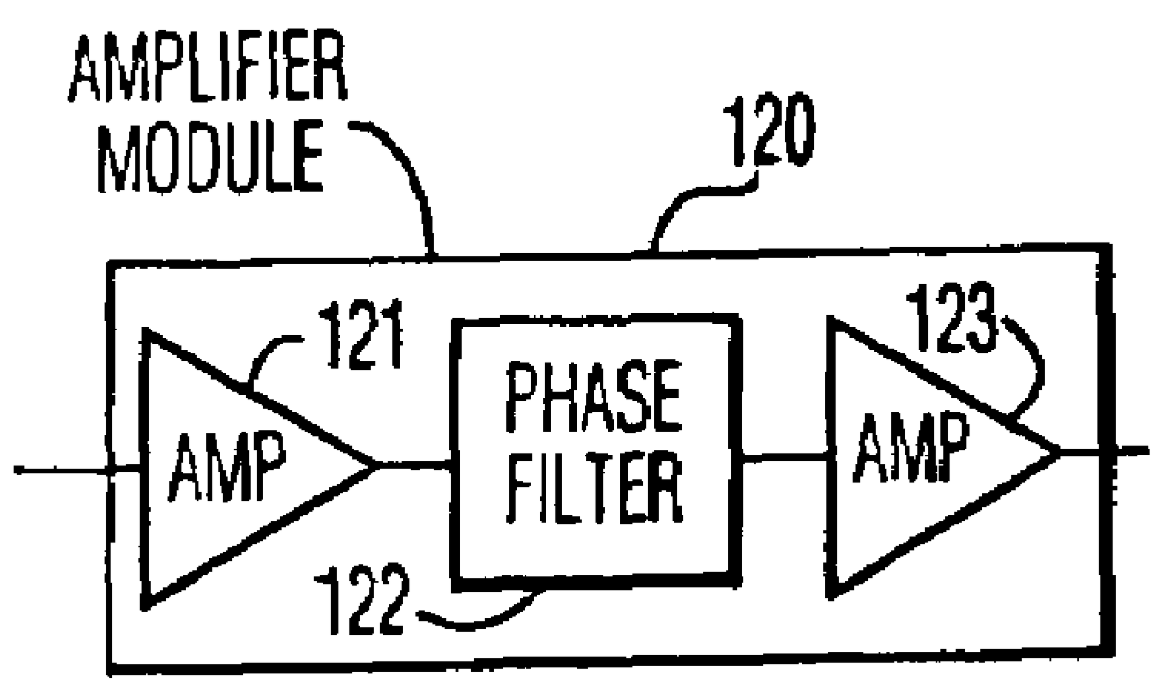


FIG. 2

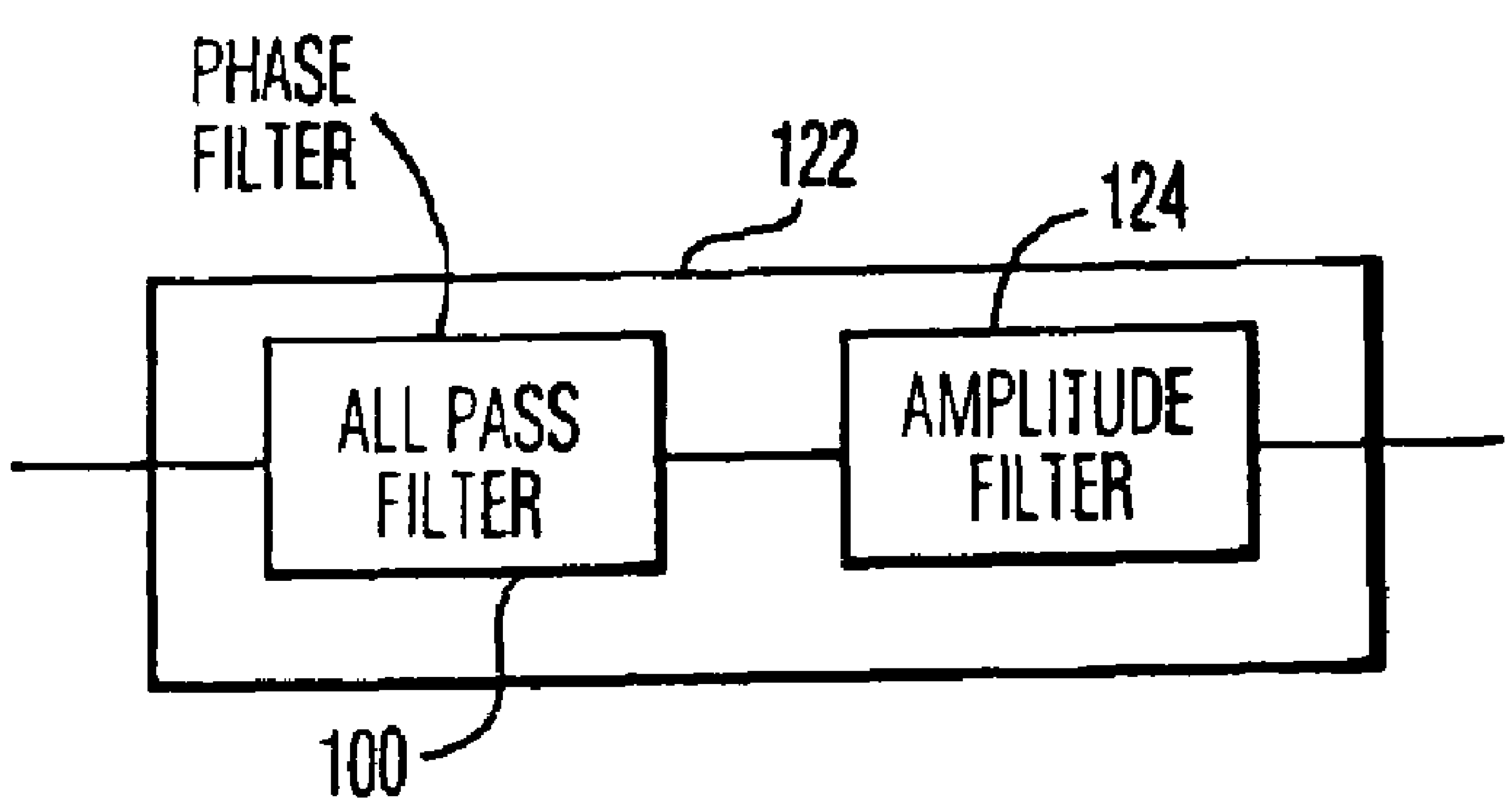


FIG. 3

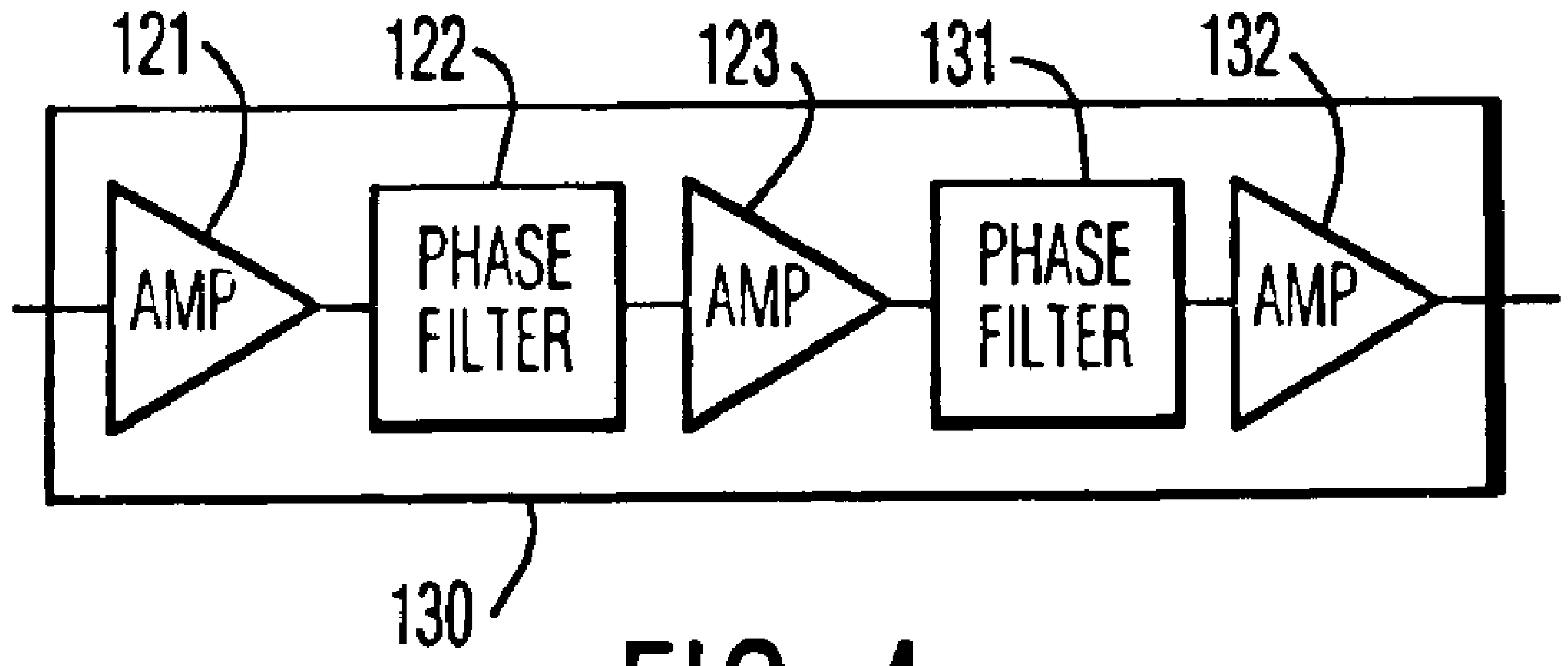


FIG. 4

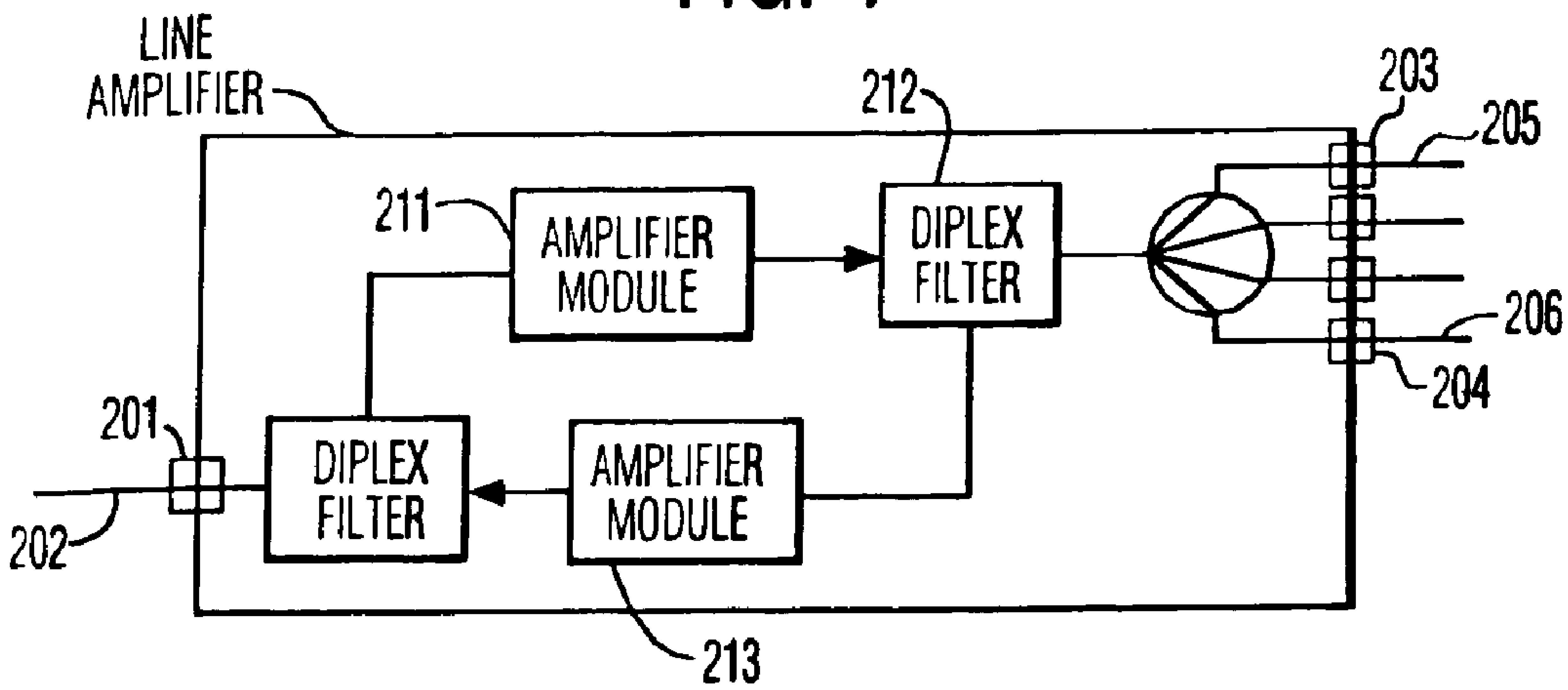


FIG. 5

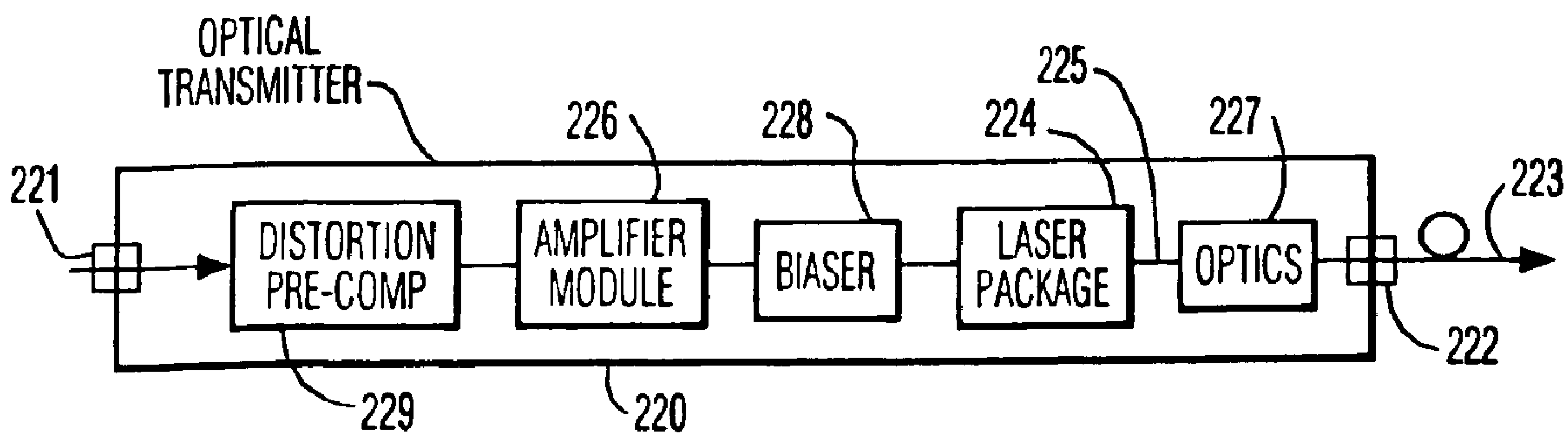


FIG. 6

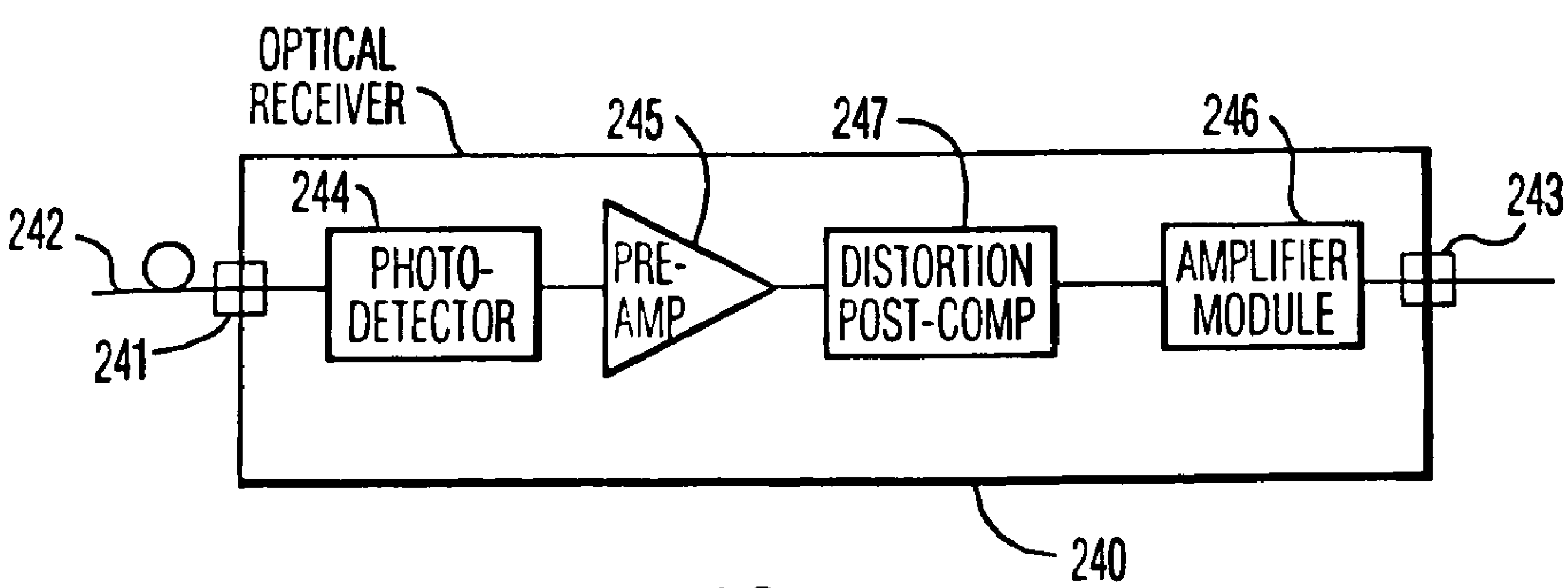
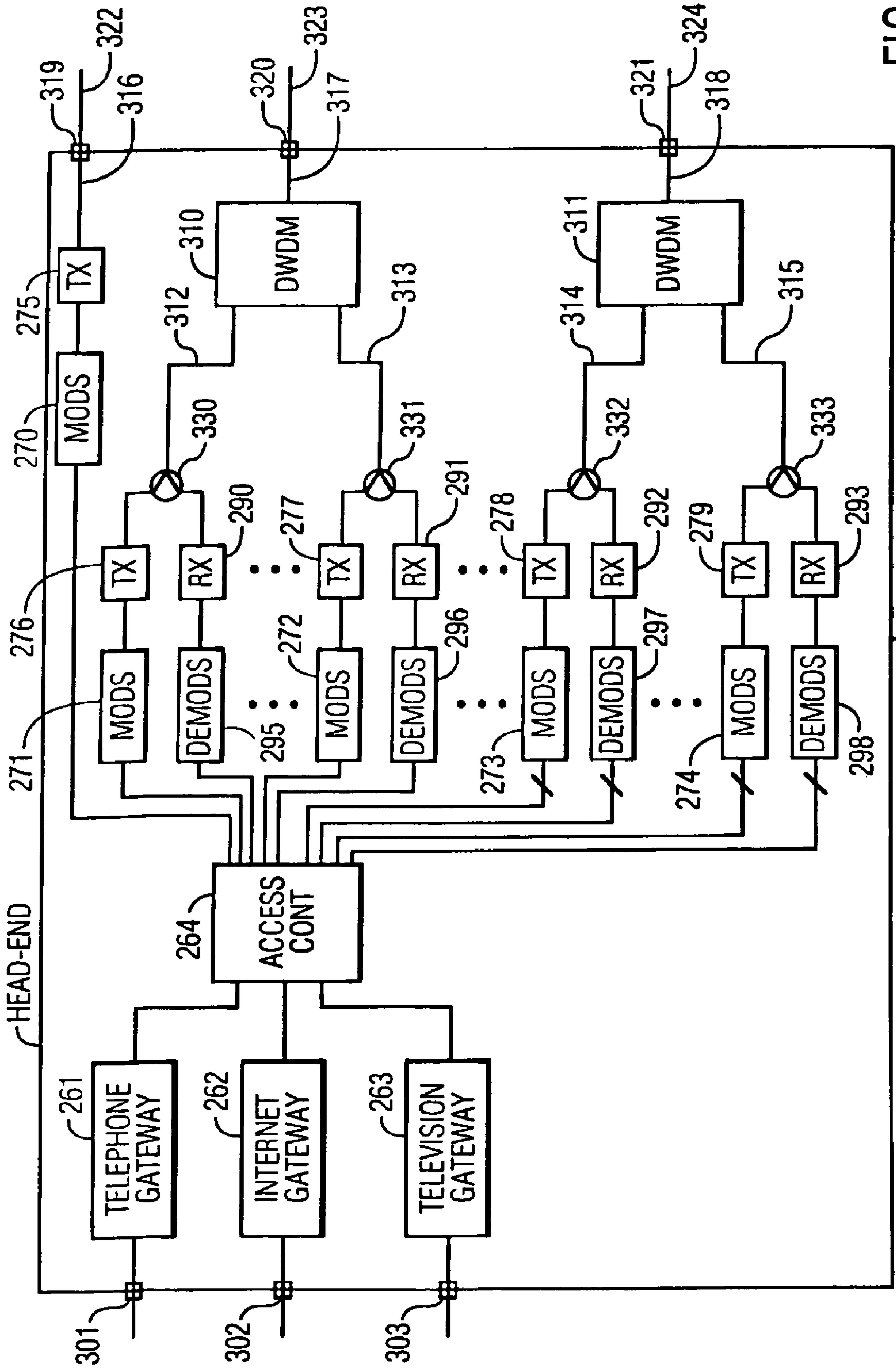


FIG. 7


HEAD-END
260
TELEPHONE GATEWAY
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INTERNET GATEWAY
262
TELEVISION GATEWAY
263
ACCESS CONT
264
MODS
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271
272
273
274
TX
275
276
277
278
279
RX
290
291
292
293
DEMODS
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297
298
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302
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DWDM
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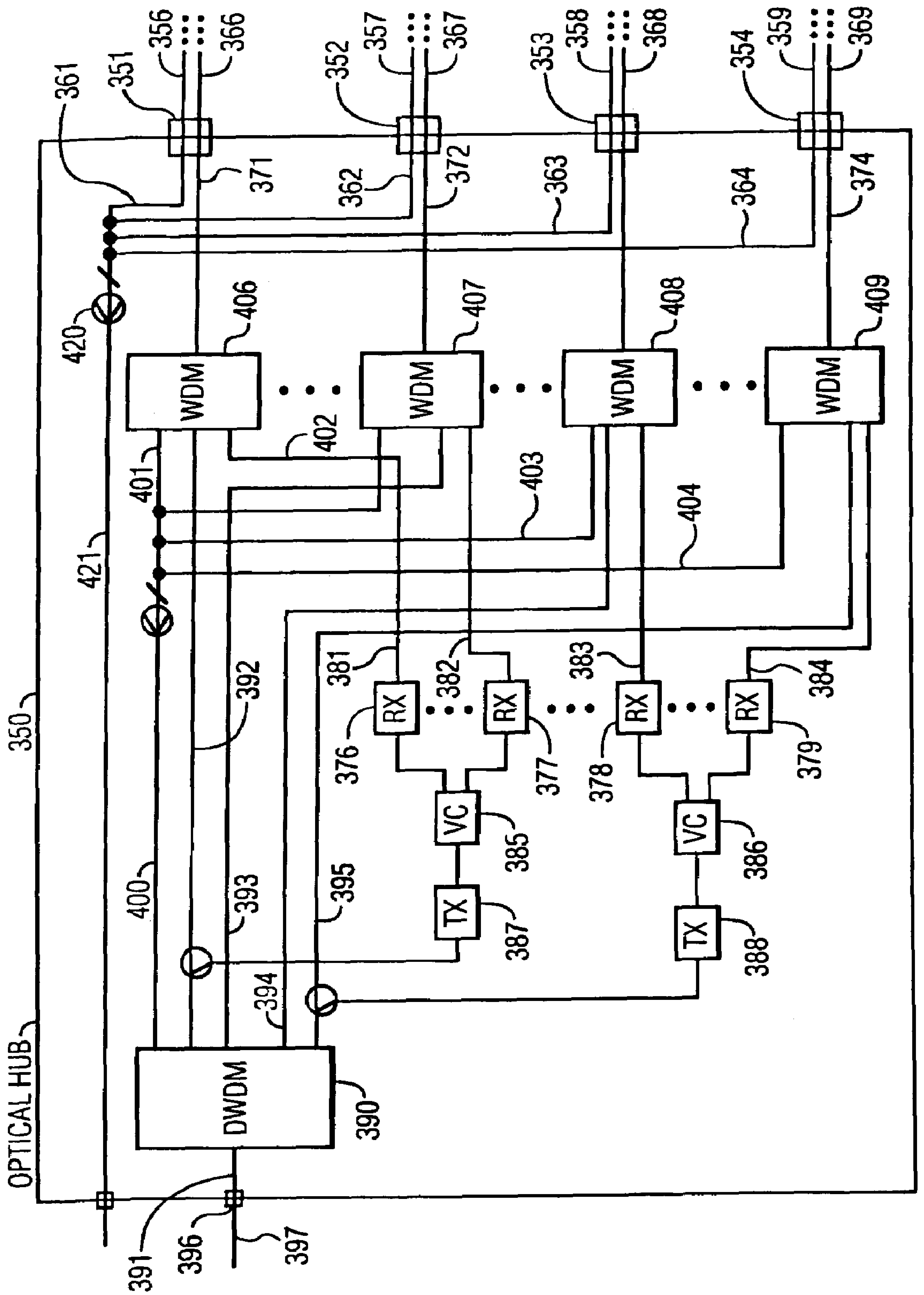
FIG. 8

FIG. 9


OPTICAL HUB
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372
374
WDM
WDM
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DWDM
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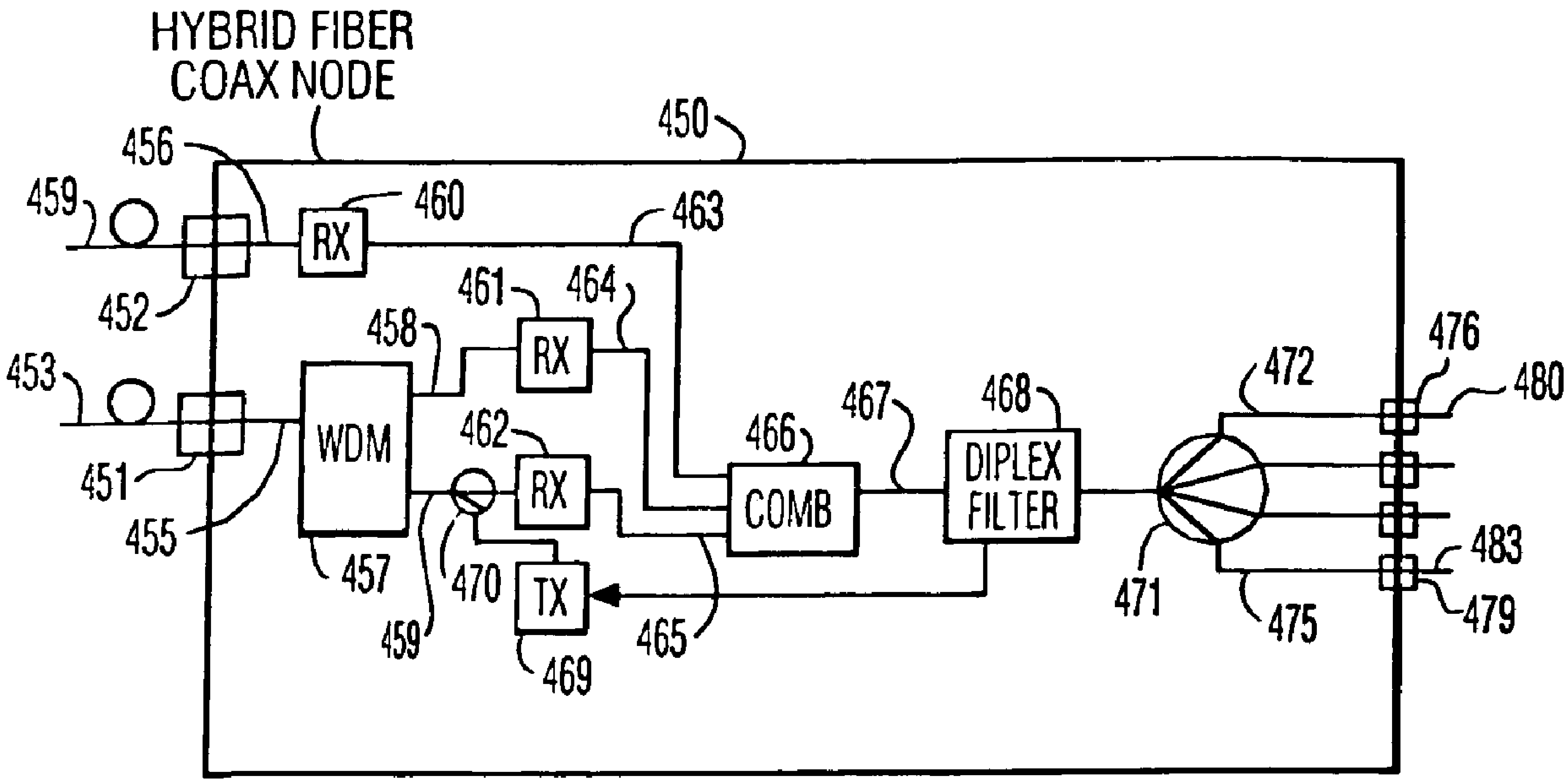
HYBRID FIBER
COAX NODE
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459
460
RX
463
452
461
464
458
RX
476
480
453
472
468
467
466
462
WDM
DIPLEX
FILTER
RX
COMB
451
455
470
TX
471
457
483
475
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465
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FIG. 10

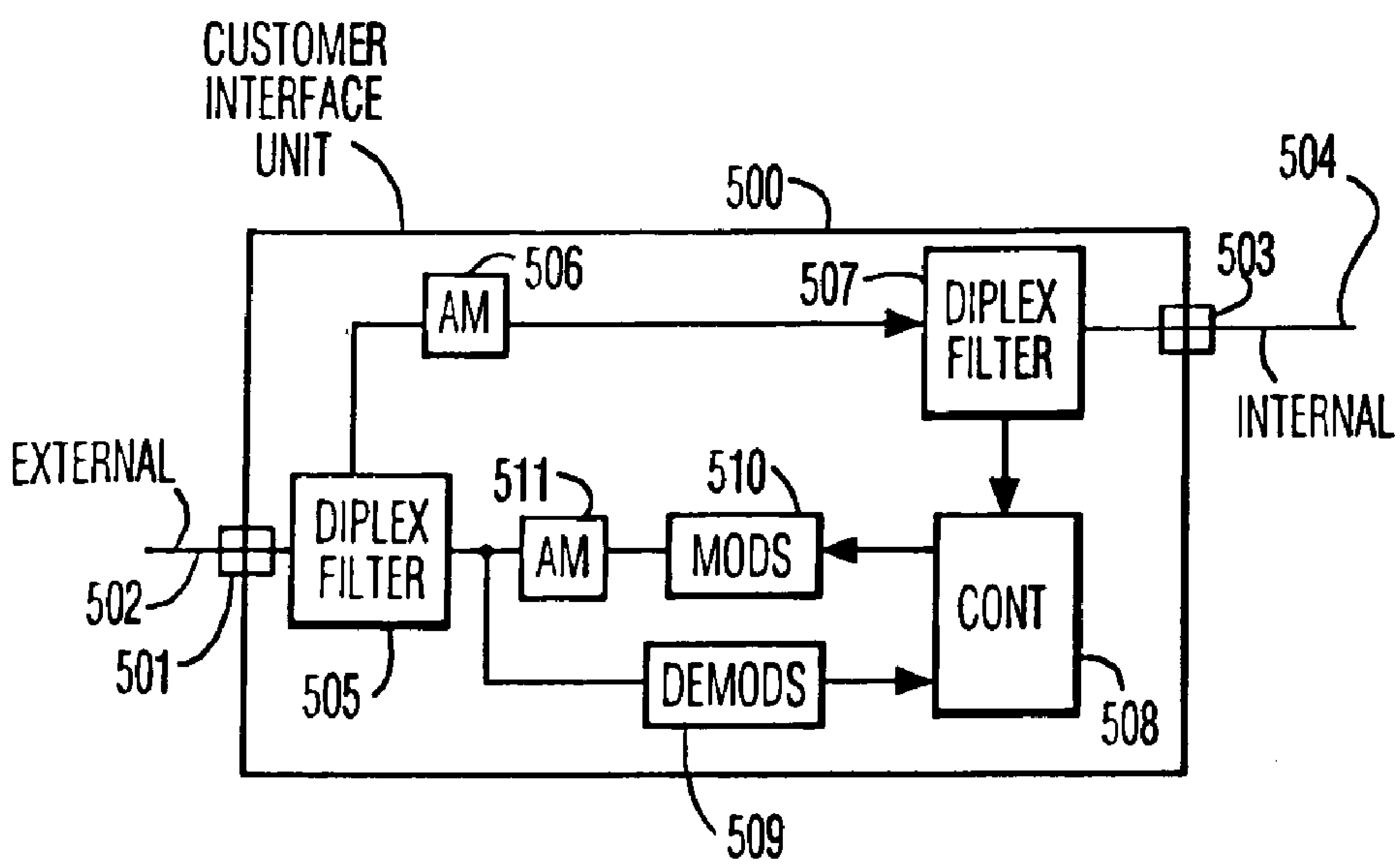
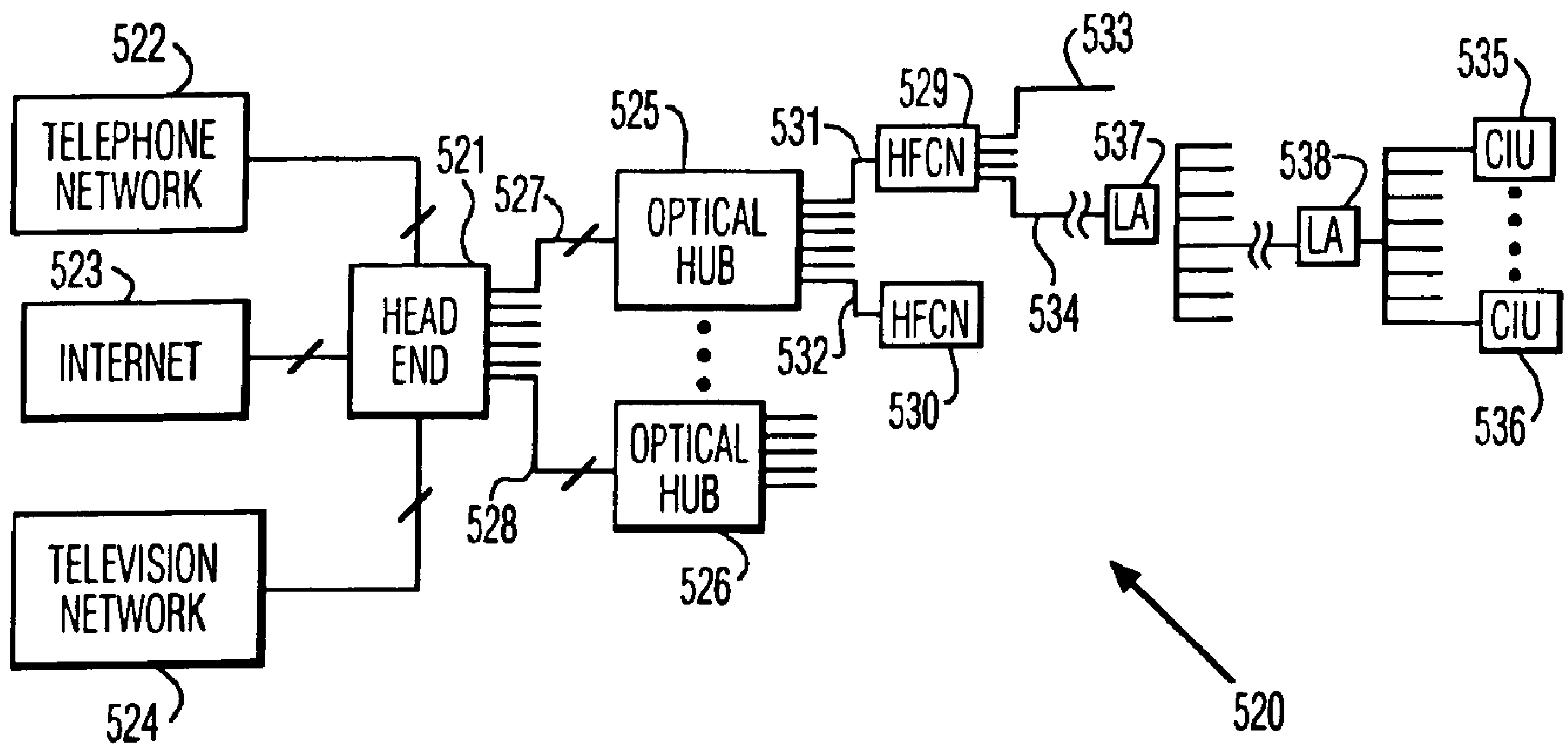

CUSTOMER
INTERFACE
UNIT
500
504
506
AM
507
DIPLEX
FILTER
503
INTERNAL
EXTERNAL
511
510
DIPLEX
FILTER
AM
MODS
CONT
502
501
DEMODS
505
508
509

FIG. 11


522
TELEPHONE NETWORK
523
INTERNET
524
TELEVISION NETWORK
521
HEAD END
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525
OPTICAL HUB
OPTICAL HUB
526
531
532
529
HFCN
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FIG. 12

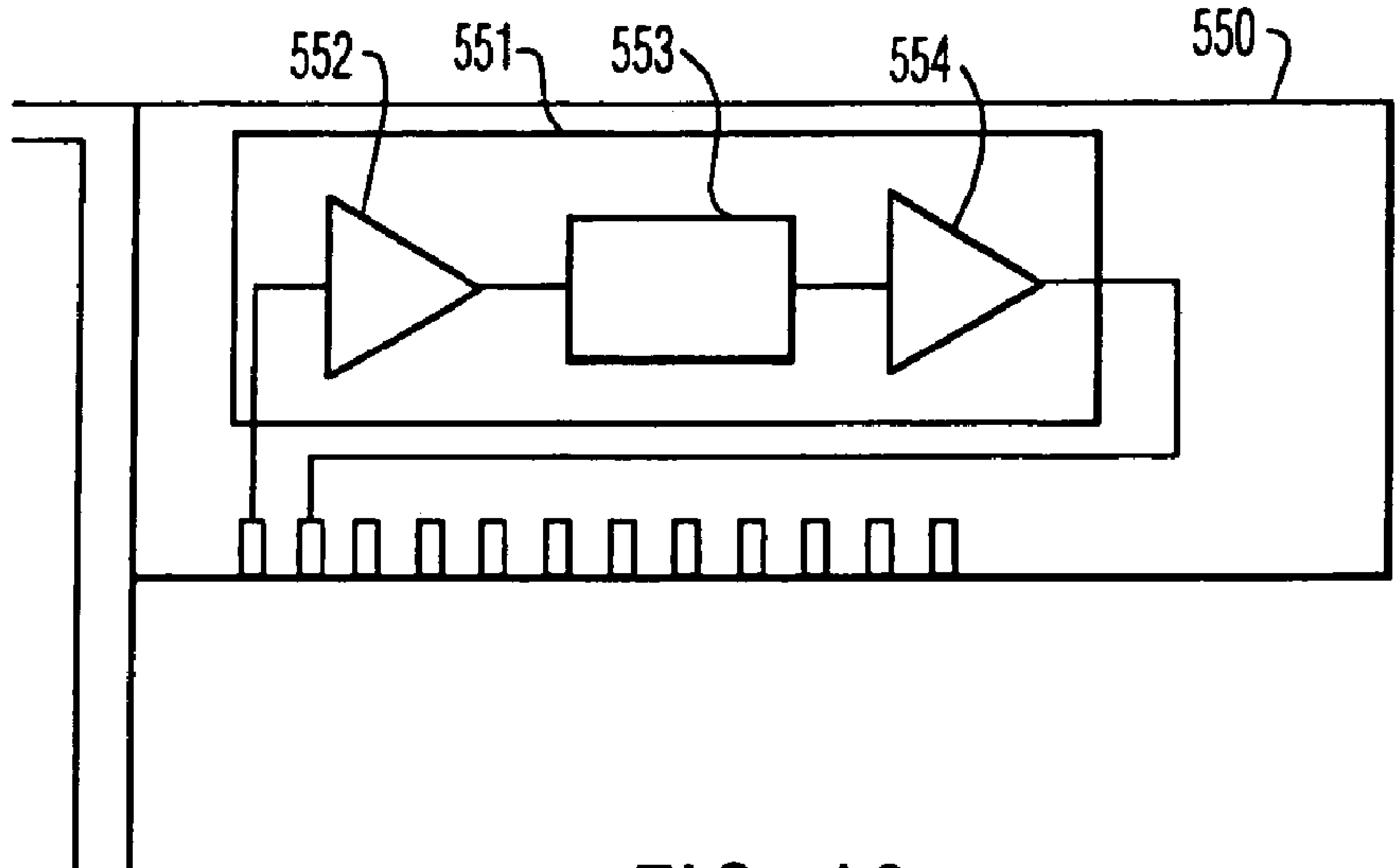
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FIG. 13

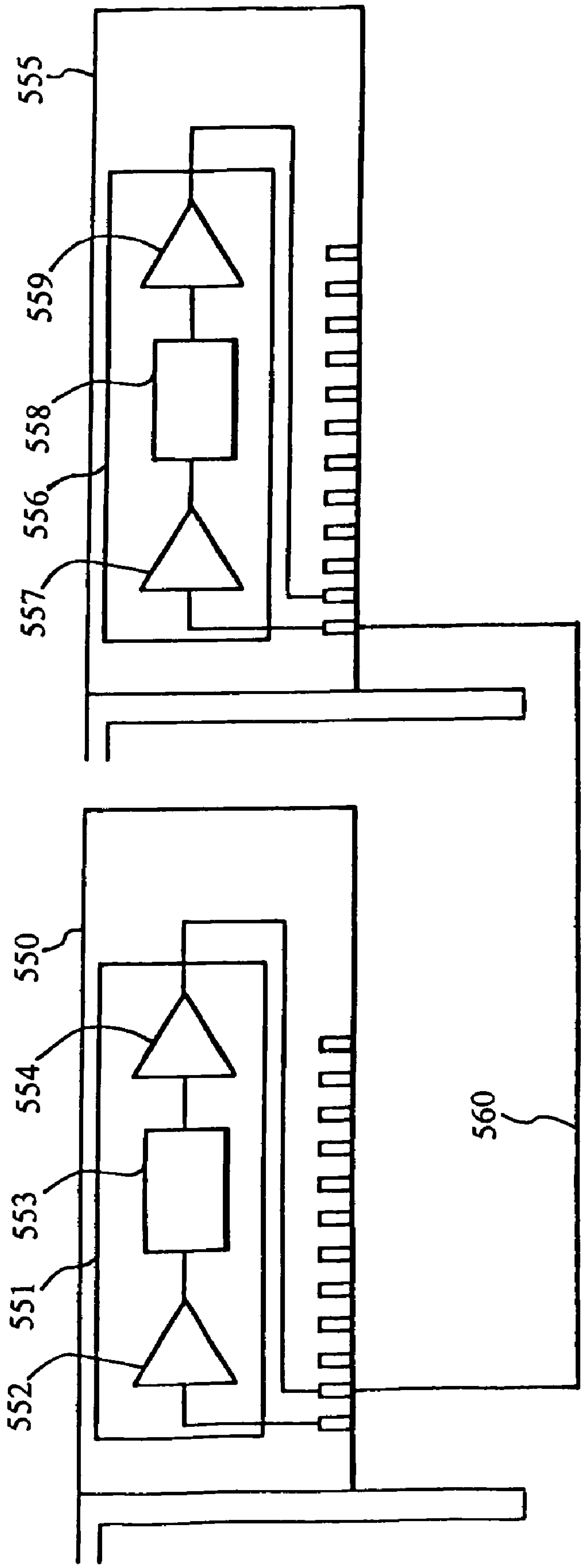

FIG. 14

AMPLIFIER COMPOSITE TRIPLE BEAT (CTB) REDUCTION BY PHASE FILTERING

CROSS REFERENCE TO RELATED APPLICATION

The present application claims the benefit under 35 USC 120 as a divisional application of utility application Ser. No. 09/474,295, filed Dec. 29, 1999, and now granted as U.S. Pat. No. 6,788,169 B1. the disclosure of which is herein incorporated by reference.

FIELD OF THE INVENTION

The invention is related to the field of cable television systems and more specifically with amplification of multi-carrier video signals in cable television systems.

BACKGROUND OF THE INVENTION

In a cable television system (CATV), television programs are provided at a central head-end. The programs are distributed from the head-end through branching tree-like networks of optical fibers to a multitude of hybrid fiber cable nodes (HFCNs) in respective local communities. Then further distributed from the HFCNs through branching tree-like networks of coaxial cables to customer interface units (CIUs), also called cable terminations.

Currently, many of these systems are beginning to provide additional communication services such as telephone services and computer networking services (e.g. internet connection) through the cable television system. Telephone and computer networking services require bi-directional communication in the cable television system. Forward data signals for these additional services are transmitted in a manner similar to television signals, as described above, and return data signals are transmitted through the same path in the reverse direction. That is, return signals are collected from the CIUs through the branching coaxial cable networks to the HFCNs, back through the HFCNs, and back through the branching optical fiber network to the head-end.

At the head-end, a multitude of electronic forward information signals for broadcast television and additional services (telephone and computer communications) are used to modulate respective carrier signals of different frequencies. The modulated carrier signals are combined into an electronic multi-carrier forward signal that is used to modulate a forward laser beam to produce an optical forward signal carried by the forward laser beam. The modulated laser beam, carrying the optical forward signal, is transmitted through the optical fiber network to a multitude of the HFCNs. At each local node an optical detector coverts the optical forward signal back into an electronic forward signal. The reconverted electronic forward signal is transmitted from the HFCNs through the coaxial cable network to CIUs at homes and businesses of customers.

At the cable termination, telephone and computer equipment of the customer, are connected to the CIUs. The customer's equipment produce electronic return signals that are transmitted by the CIUs into the coaxial cable network. The return signals are multi-carrier modulated signals similar to the forward signals. The return signals travel back through the tree-like coaxial cable network to the HFCNs. In the HFCNs, the return signals are separated from the forward signals by diplex filters. The separated return signals are used to modulate a return laser beam to produce a multi-carrier optical return signal carried by the return laser beam. The optical return signal is transmitted back through the tree-like optical fiber network to the head-end where the optical return signals are converted back into electronic return signals by an optical detector for the return signals. The electronic return signals are demodulated and used for telephone and computer communications.

Requirements for signal to noise ratio (S/N) at the cable termination together with limits on the allowed optical power, limit the length of one-directional optical transmission of analog television signal to around 100 km. In the coaxial cable network, line amplifiers are required at intervals of approximately 300 to 350 meters in order to maintain the amplitude of the high frequency electronic signals. The line amplifiers in the coaxial cable network produce distortions that result in additional noise that further limits the length of signal transmission.

In bi-directional transmission, the introduction of return light beams in the optical fiber network results in crosstalk as additional noise that further reduces the range of cable broadcasting. The line amplifiers must be bi-directional and both the forward and return amplifiers produce distortions that result in increased noise in both the forward and return directions which further limits transmission distance.

An important part of the distortion caused by power amplifiers is the composite triple beat (third order) distortion. In addition to the two amplifiers in each bi-directional line amplifier, the optical transmitters, optical receivers, and CIUs each include a power amplifier. The distortions are cumulative as the signal passes through a multitude of power amplifiers from the source of the signal to the CIUs, and the distortions from return signal amplification in the line amplifiers also adds to the distortion of the forward signals. The result is that signal transmission in bi-directional systems is even more limited by noise than in previous one-directional systems.

Those skilled in the art are directed to the following citations. U.S. Pat. No. 4,947,386 to Preschutti discloses a broadband network with a bi-directional amplifier. U.S. Pat. No. 5,343,158 to Gris discloses another bi-directional amplifier. U.S. Pat. No. 5,519,434 in FIG. 2 discloses an all pass filter.

The above references are hereby incorporated herein in whole by reference.

SUMMARY OF THE INVENTION

A broadband communication system includes multi-stage power amplifier systems for amplifying the power of radio-frequency (RF) communication signals. Each stage of the amplifier systems result in composite triple beat (CTB) distortion, and if the phase of the CTB distortions are approximately the same (i.e. are in-phase), then the amplitudes of the distortions are added (i.e. "20 dB" rule). The amplifier system of the invention includes one or more phase filters positioned in series between the power amplifier stages. The phase filters are adapted to shift the phase of the communication signals, so that, the phase of CTB distortions, resulting from the amplification of the communication signals in the amplifier stages between the phase filters, are substantially different (i.e. out-of-phase). Thus, only the power of the CTB distortions are added (i.e. "10 dB" rule).

Preferably, the shift in-phase response of the phase filters, over the frequency band to be amplified by the power amplifier, is at least 30 degrees over at least 15% of the band. Preferably, the multi-stage power amplifier is provided as an amplifier unit on a plug-in card to allow the invention to be easily implemented on existing equipment such as line amplifiers.

The invention includes a particular phase filter that allows the phase of a communication signal to be reliably shifted by amounts controlled by selecting the properties of the components of the phase filter.

The invention also includes a bi-directional line amplifier that uses the multi-stage phase shifted power amplifier of the invention. The invention is especially useful for such line amplifiers because several such amplifiers are often required in series along the coaxial cable networks of a broadband network system. It is an important aspect of the invention that phase filters be used to prevent the amplitudes of CTB distortions of the series of line amplifiers from being combined additively.

The invention also includes an optical transmitter using the multi-stage phase shifted power amplifier of the invention. The power amplifier is required to provide the correct power for modulating the laser beam. These optical transmitters are used in the cable television system to transmit the communication signals through optical fibers in a forward direction from the head-end through hybrid fiber cable nodes (HFCNs) and to transmit return signals back through the optical fibers from the HFCNs to the head-end. The CTB distortion resulting from the power amplification in the optical transmitters accumulates with the CTB distortions of the line amplifiers to produce noise in the system.

The invention also includes an optical receiver using the multi-stage phase shifted power amplifier of the invention. These receivers usually include a preamplifier to amplify the signal for post-processing the signal and after post-processing the signal is amplified for further distribution. These optical receivers are used to receive the forward communication signals from the optical fibers at the HFCNs and provide the amplified signal into the coaxial cable networks. Also, these optical receivers are used to receive the return communication signals from the optical fibers at the head-end. The CTB distortion resulting from the power amplification in the optical receivers accumulates with the CTB distortions of the line amplifiers and power amplifiers in the optical transmitters to produce noise in the system.

The invention also includes the head-end, an optical hub, and HFCNs that use the transmitters and receivers of the invention that utilize the multi-stage phase shifted power amplifier of the invention.

The invention reduces the accumulated amplitude of the different CTB distortions produced by power amplifiers in several different types of equipment in the communications link of a cable television system. Both, the CTB distortions in the forward signal between the head-end and the CIUs are reduced and the CTB distortions in the return signals from the CIUs to the head-end are reduced.

Those skilled in the art will understand the invention and additional objects and advantages of the invention by studying the description of preferred embodiments below with reference to the following drawings that illustrate the features of the appended claims:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an all pass filter of the invention.

FIG. **2** shows an amplifier module of the invention using a phase filter.

FIG. **3** illustrates details of the phase filter of FIG. **2** including the all pass filter of FIG. **1**.

FIG. **4** shows another embodiment of the amplifier module of the invention.

FIG. **5** illustrates portions of a bi-directional line amplifier of the invention.

FIG. **6** show portions of an optical transmitter of the invention.

FIG. **7** illustrates portions of an optical receiver of the invention.

FIG. **8** shows portions of a specific embodiment of a head-end of the invention.

FIG. **9** illustrates portions of an optical hub of the invention.

FIG. **10** illustrates portions of an HFCN of the invention.

FIG. **11** illustrates portions of a customer interface unit (CIU) of the invention.

FIG. **12** shows a cable television system of the invention.

FIG. **13** illustrate portions of a plug-in card of the invention.

FIG. **14** illustrates two plug-in cards in accordance with a further aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following description the same labels in different figures indicate similar elements, but similar elements may be identified by different labels for convenience of description.

FIG. **1** illustrates an all pass filter **100** of the invention. The all pass filter includes: an input terminal **101** and an output terminal **102**; a capacitor **103** connected between the input and output terminals; an inductor **104** connected between the input and output terminals; a transformer **105** with first windings **106** connected in a direction between the first terminal and a third terminal **107** and the second windings **108** connected in the same direction between the third terminal and the output terminal, the first windings **106** and the second windings **108** being connected in series; and a capacitor **110** and an inductor **111** connected in series between the third terminal and ground. The order of the connection of capacitor **110** and inductor **111** is arbitrary. The location of the dots on transformer **105** indicate that the direction of winding **108** is actually opposite to the way it is shown. This notation is customarily used in the art to simplify schematic representations.

The particular all pass filter **100** is especially useful for changing the phase of a multi-carrier electronic signal with a range of carrier frequencies of approximately 5-50 MHz or approximately 50-550 MHz. Preferably, the properties of the capacitors, inductors and transformer are selected so that, the phase of the multi-carrier signal at the output terminal is shifted at least 15 degrees with respect to the phase at the multi-carrier signal at the input terminal.

FIG. **2** shows an amplifier module **120** of the invention includes: a first amplifier stage **121** of one or more amplifiers for amplifying a first signal to produce a second signal; a first phase filter **122** for changing the phase of the second signal to produce a third signal; and a second amplifier stage **123** of one or more amplifiers for amplifying the third signal to produce a fourth signal. The phase filter alters the phase of the multi-carrier signal, so that, the amplitude of composite triple beat (CTB) distortion produced by the first amplifier stage is not directly added to the amplitude of the CTB distortion produced by the second amplifier stage.

If the CTB distortion produced by the second amplifier stage has the same phase as the CTB distortion produced by the first amplifier stage, then the amplitudes of the two CTB distortions are directly added resulting in a larger CTB distortion. This is the so called 20 dB rule. In communication systems, the CTB distortion results in noise in the system and needs to be minimized. Generally, the amplifier stages change the phase slightly, so that, there will be some small phase difference between the two CTB distortions which slightly reduced the total CTB distortion.

If the phase of the CTB distortion produced by the second amplifier was exactly 180 degrees different from the phase of the CTB distortion produced by the first amplifier stage (e.g. they were out-of-phase) and the CTB distortions were identical then these two CTB distortions would cancel out and there would be no total CTB. However, the change in-phase produced by a phase filter is dependent on frequency so that the CTBs can not be made 180 degrees out-of-phase over the whole frequency range. Also, the CTB distortion produced by the amplifiers will be different even if the amplifiers stages are identical, which they generally are not, because the input power levels are different because the input signal to the second amplifier has already been amplified. Also, the CTB distortion generally depends on the amplitude of the input signal which changes during communication. If there are more than two amplifier stages, attempting to cancel out CTB distortions becomes even more problematical. Preferably, the phase shift due to the phase filter is in the opposite direction to the phase shift produced by the first amplifier stage, but is preferably much larger than the phase shift typically produced by amplifiers that are used in broadband networks.

The purpose of the phase shift is not to compensate for the phase shift due to the amplifier stages, but to provide an even greater phase shift so that the CTB distortions are at least partially out-of-phase so that noise due to distortion is reduced.

Preferably, the phase filter of FIG. **2** changes the phase of the output signal of the first amplifier stage so that, the total CTB distortion is reduced in relation to a similar system of amplifier stages without the phase filter. Preferably, the phase of the input signal of the second stage is at least 30 degrees for at least 15% of the frequency band of the multi-carrier signal and more preferably at least 60 degrees different than the phase of the input signal of the first amplifier stage. Even more preferably, the phase of the input signal to the second stage is at least 90 degrees and even more preferably approximately 180 degrees out-of-phase with the input to the first amplifier stage. In this case, the total CTB distortion resulting from the amplifier module will be substantially less than the total of the amplitudes of the CTBs produced by each of the amplifier stages.

FIG. **3** illustrates the phase filter **122** of FIG. **2** and includes: an all pass filter **100** of FIG. **1**; and an amplitude filter **124**. All pass filters and amplitude filters are well known in the art. The all pass filter of FIG. **3** may be any known all pass filter capable of changing the phase of the carrier signals of a multi-carrier broadband signal by at least approximately 30 degrees over at least approximately 15% of the band, but is preferably, the all pass filter of FIG. **1**. Preferably, the all pass filter and amplitude filter are combined into a single circuit providing both these functions.

FIG. **4** shows an amplifier module **130** of the invention which is similar to the amplifier module of FIG. **2**, but further includes: a second phase filter **131** for changing the phase of the fourth signal to produce a fifth signal; and a third amplifier stage **132** of one or more amplifiers for amplifying the fifth signal to produce a sixth signal. The second phase filter is similar to the first phase filter, but preferably shifts the phase by approximately twice as much and in the opposite direction, so that, the phases of the inputs of the amplifier stages differ by at least approximately 30 degrees from the phase at either of the other two inputs. In this embodiment the phase of the input signal to each amplifier stage is preferably at least approximately 30 degrees different than the phase of the input signal of any other amplifier stage, and more preferably, the phases are different by at least approximately 60 degrees and less than approximately 120 degrees.

FIG. **5** illustrates portions of a bi-directional line amplifier **200** of the invention using the amplifier module of FIG. **2**. The bi-directional amplifier includes: a connector **201** for a first coaxial cable **202**; connectors **203-204** respective second coaxial cables **205-206**; a first diplex filter **210** for separating higher-frequency signals from the signals in the first coaxial cable; a first amplifier module **211** for amplifying the separated higher-frequency signals as an input signal and transmitting the amplified higher-frequency signal into the second coaxial cables as an output signal; a second diplex filter **212** for separating lower-frequency signals from the signals in the second coaxial cables; a second amplifier module **213** for amplifying the separated lower-frequency signals as an input signal and transmitting the amplified lower-frequency signals into the first coaxial cable as an output signal. The line amplifier further includes a splitter for providing copies of the amplified higher-frequency signals into each of the second coaxial cables **205-206** and providing respective lower-frequency signals from each of the second coaxial cables to the second diplex filter **212**.

At least one of the amplifier modules is an amplifier module similar to amplifier module **120** of FIG. **2**, and more preferably, both amplifier modules are modules similar to the module of FIG. **2**. The above discussion of amplifier module also generally applies to these amplifier modules. The components of the all pass filters of amplifier module **211** are selected to produce a phase difference of at least 30 degrees over 15% of a frequency band of 50-550 MHz or 65-550 MHz, and the components of the all pass filters of amplifier module **213** are selected to produce a phase difference of at least 30 degrees over 15% of a frequency band of 5-50 MHz or 5-65 MHz.

FIG. **6** show portions of an optical transmitter **220** of the invention which, includes: an input connection **221** for an electronic signal; an output connection **222** for an optical path (such as optical fiber **223**); a laser package **224** for producing a modulated laser beam **225**; an amplifier module **226** for amplifying the electronic signal to produce an amplified electronic signal directed to the laser package; and an optics system **227** for directing the modulated laser beam into the optical fiber. The laser package may be either: a continuous laser and an external modulator; or a DFB laser. If the laser package is a DFB laser then a biaser **228** is required for biasing the amplified electronic signal for use as the bias current of the DFB laser.

The transmitter further includes a distortion pre-compensator **229** for distorting the electronic signal to compensate for at least a portion of the CTB produced in the amplifier module. The pre-compensator may also compensate for composite second order (CSO) distortions caused by the amplifier modules along with CTB and CSO distortions due to the laser modulation, and transmission of the optical signal through optical fiber that is does not exhibit zero dispersion at the laser wavelength. The pre-compensator may also shape the signal so that larger excursions are reduced to prevent large negative excursions in the signal from going below a laser cut-off current and large positive excursions causing increased distortions.

Amplifier module **226** is similar to amplifier module **120** of FIG. **2** and the above discussion of amplifier module **120** also generally applies to amplifier module **226**. The components of the all pass filter of amplifier module **226** are selected to produce a phase difference of at least 30 degrees over at least 15% of the frequency band of the electronic signal.

FIG. 7 illustrates portions of an optical receiver **240** of the invention which includes: a connector **241** for an optical path (e.g. optical fiber **242**); an output terminal **243** for an electrical path; a photo-detector **244** for converting an optical signal in the optical fiber into an electronic signal; a preamplifier **245** for amplifying the electronic signal to produce a preamplified signal; and an amplifier module **246** for amplifying the preamplifier signal to produce an amplified signal at the output terminal. The optical receiver also includes a distortion post-compensator **247** for compensating for at least a portion of CTB distortion produced by amplifier module **246**. The post-compensator may also compensate for composite second order (CSO) distortions caused by the amplifier module along with CTB and CSO distortions due to laser modulation and transmission of the optical signal through optical fiber that is does not exhibit zero dispersion at the laser wavelength. Preferably, the bandwidth of digital signals is less than an octave and the post-compensator includes a filter for filtering out essentially all the CSO distortions. More preferably, the bandwidth of digital signals is less than half an octave and the filter of the post-compensator also filters out essentially all the fourth order distortions. If a pre-compensator included signal shaping, then preferably, the post-compensator also includes signal shaping to restore the signal to its original shape before signal shaping in the transmitter.

Amplifier module **246** is similar to amplifier module **120** of FIG. **2** and the above discussion of amplifier module **120** also generally applies to amplifier module **246**. The components of the all pass filter of amplifier **246** are selected to produce a phase difference of at least 30 degrees over at least 15% of the frequency band of the electronic signal.

FIG. **8** shows portions of a specific embodiment of a head-end **260** of the invention, which includes: gateway apparatus **261-263** for providing electronic base-band forward signals and for receiving electronic base-band return signals; an access controller **264** for controlling the routing of the electronic base-band forward and return signals between the gateway apparatus and other portions of the head-end; one or more modulators **270-274** for modulating radio-frequency carrier signals with the electronic base-band forward signals to produce multi-carrier electronic forward signals; respective optical transmitters **275-279** for converting the multi-carrier electronic forward signals into multi-carrier optical forward signals in respective optical paths, the optical signal's having optical wavelengths, the wavelengths of the optical signals from some transmitters being different from the wavelengths of optical signals from other transmitters; one or more optical receivers **290-293** for converting multi-carrier optical return signals in respective optical paths into the multi-carrier electronic return signals; and respective demodulators **295-298** for demodulating the multi-carrier electronic return signals to produce the electronic base-band return signals. The gateway apparatus includes a telephone gateway **261** with connection **301** for bi-directional telephone communication with a telephone network; an internet gateway **262** with connection **302** for bi-directional computer communication with a computer network; and a television gateway **263** with connection **303** for bi-directional video communication with a television network.

The head-end further includes one or more dense wavelength division multiplexers **310-311**. Each multiplexer, such as multiplexer **310**, combines multi-carrier optical forward signals from multiple optical paths **312-313** with different respective optical wavelengths into a single common optical path **317** and separates multiple multi-carrier optical return signals with different respective optical wavelengths from the single common optical path into the multiple respective optical paths. Connectors **319-321** connect respective optical paths **316-318** with respective optical fibers **322-324**.

The head-end further includes one or more optical splitters **330-333** for connecting respective optical transmitters **276-279** and respective optical receivers **290-293** to the same end of respective optical paths **312-315**, so that, the respective transmitter can transmit the optical forward signal with approximately the same optical wavelength as the optical wavelength of the optical return signal received by the respective optical receiver. The optical forward signals include one or more analog television signals with carrier frequencies of approximately 50-550 MHz or 65-550 MHz transmitted through optical fiber **322**. Forward digital signals, transmitted to optical hubs discussed below, have carrier frequency bands of approximately 550-840 MHz and potentially in the future 840-1260 MHz. Return digital signals from optical hubs have carrier frequency bands of 400-600 MHz and 600-900 MHz and potentially in the future of 900-1350 MHz.

The transmitters **275-279** of the head-end are similar to the transmitter **220** of FIG. **6**, and the receivers **290-293** of the head-end are similar to the receiver **240** of FIG. **7**. Thus, each transmitter and receiver includes an amplifier module similar to the amplifier module **120** of FIG. **2** which includes the all pass filter **100** of FIG. **1**.

FIG. **9** illustrates portions of an optical hub **350** of the invention, which includes: a multitude of connectors **351-354** for connecting respective optical fibers **356-359** for respective hybrid fiber coax nodes (HFCNs) to respective optical paths **361-364**; and for connecting respective optical fibers **366-369** for respective HFCNs to respective optical paths **371-374**. The optical hub also includes: a multitude of optical receivers **376-379** for converting first multi-carrier optical return signals in respective optical paths **381-384** into respective first multi-carrier electronic return signals, the first multi-carrier signals each includes a multitude of base-band signals modulating respective first carrier signals; one or more upconverters **385-386**, each for converting two or more first multi-carrier return signals into a single second multi-carrier electronic return signal, the second mufti-carrier return signals each includes all the base-band signals of the respective two or more first return signals that were combined, the base-band signals modulating respective second carrier signals, the second carrier signals having radio frequencies substantially higher than the radio frequencies of the first carrier signals; and respective optical transmitters **387-388** for converting the second mufti-carrier electronic return signals into second mufti-carrier optical return signals in respective optical paths, the optical signals having optical wavelengths, the wavelengths of the optical signals from the transmitters being different from the wavelengths of optical Signals from other transmitters. The optical hub further includes a WDM **390** for combining the second multicarrier optical return signals into a common optical path **391** and for separating forward digital signals from the common optical path into first optical paths **392-393** for respective HFCNs. Connector **396** is connected to optical path **391** and is provided for connecting an optical fiber **397** between the optical hub and the head-end.

The optical hub further includes one or more first splitters for routing a forward optical signal for digital broadcast television from a single optical path **400** into similar portions of the forward optical signal in second optical paths **401-404** for respective HFCNs. The optical hub further includes a multitude of a wavelength division multiplexers **406-409** for respective HFCNs. Each multiplexer combining optical forward signals from one of the first separate optical paths **392-395** and one of the second optical paths **401-404** into one of the common optical paths **366-369** for a respective HFCN and for separating a return signal from the respective common optical path of paths **366-369** for the HFCN into a separate return optical path of paths **381-384** for a respective optical receiver. The wavelength of the return optical signal for an HFCN must be different than the wavelengths of the forward optical signals for that HFCN so that the respective WDM can separate the low frequency return optical signal from the forward optical signal from the head-end. The optical hub further includes one or more second splitters **420** for routing a forward optical signal for analog broadcast television from a single optical path **421** into similar portions for the forward signal in third optical paths **361-364** for respective HFCNs.

The up converters of the optical hub may be provided by one skilled in the art by connecting demodulators (not shown) with modulators (not shown).

The transmitters **387-388** of the optical hub are similar to the transmitter **220** of FIG. **6**, and the receivers **376-379** of the optical hub are similar to the receiver **240** of FIG. **7**. Thus, each transmitter and receiver of the optical hub includes an amplifier module similar to the amplifier module **120** of FIG. **2** which includes the all pass filter **100** of FIG. **1**.

FIG. **10** illustrates portions of an HFCN **450** of the invention, which includes: optical connectors **451-452** for connecting optical fibers **453-454** to respective optical paths **455-456**; and a WDM **457** for separating forward signals in common path **455** into separate optical signals in respective paths **458** and **459** and routing a return signal in optical path **459** into common fiber **455**. The HFCN also includes: optical receivers **460-462** for converting optical forward signals in the respective optical paths **456**, **458**,**459** into a first electronic forward signals in an respective electrical paths **463-465**; and combiner **466** combines the electrical signals in paths **463-465** into electrical path **467**. The HFCN has: a diplex filter **468** for separating electronic return signals from the electronic forward signal in the electrical path; an optical transmitter **469** for converting the separated electronic return signals in electrical path **499** into optical return signals; and a splitter **470** for combining the return signals in optical path **459**. The HFCN further includes an electronic splitter **471** for routing the electronic forward signals from electrical path **467** into electrical paths **472-475** and routing electronic return signals from electrical paths **472-475** into electrical path **467**. Also, connectors **476-479** are provided to connect coaxial cables **480-483** to respective electrical paths **472-475**. Note that in this case all the connected coaxial cables comprise a single coaxial cable network because all the cables share the same return channels.

The receivers **460-462** of the HFCN are similar to the receiver **240** of FIG. **7**, and transmitter **469** of the HFCN is similar to the transmitter **220** of FIG. **6**. Thus, each transmitter and receiver of the optical hub includes an amplifier module similar to the amplifier module **120** of FIG. **2** which includes the all pass filter **100** of FIG. **1**.

FIG. **11** illustrates portions of a customer interface unit (CIU) **500** of the invention which includes: a first connection **501** for an external coaxial cable network **502**; a second connection **503** for an internal coaxial cable network **504**; a first diplex filter **505** for separating the forward signals from the return signals in the external coaxial cable network; and a first amplifier module **506** for amplifying the forward signals to provide amplified forward signals into the internal coaxial cable network. The CIU further includes: a second diplex filter **507** for separating base-band return signals of the customer from the internal coaxial cable network; a controller **508** for controlling the transmission of the return signals from the customer; a demodulator **509** for providing control signals from the external coaxial cable network to the controller; a modulator **510** to modulate carrier signals with the base-band return signals to provide multi-carrier return signals from the customer; and a second amplifier module **511** for amplifying the multi-carrier return signals. The controller provides time division multiplexing of the return signals from the customer with return signals from other customer interface units connected to the same external coaxial cable network. The amplifier modules **506** and **511** are similar to the amplifier module **120** of FIG. **2** which includes the all pass filter **100** of FIG. **1**.

FIG. **12** shows a cable television system **520**, which includes: a head-end **521**; respective networks **522-524** connected to the-head-end; multiple optical hubs **525-526**; respective common fibers **527-528** connected between the multiple optical hub and the head-end. The system further includes a respective multitude of HFCNs **529-530** for each optical hub; one or more optical fibers **531-532** connected between each HFCN and the respective optical hub for the HFCN; one or more coaxial cable networks **533-534** for each HFCN; a plurality of CIUs **535-536** connected to each coaxial cable network; and a plurality of line amplifiers **537-538** inserted into each coaxial cable network. The networks **522-524** include a telephone network **522**, a computer network **523**, and a television network **524**. Each network provides bi-directional communication with the head-end to provide forward signals and receive return signals from the head-end. The head-end, optical hubs, and HFCNs contain optical receivers and optical transmitters which contain amplifier modules and the line amplifiers and customer interface units also include amplifier modules. The amplifier modules of the system of FIG. **12** are similar to the amplifier module **120** of FIG. **2** which includes the all pass filter **100** of FIG. **1**.

FIG. **13** illustrate portions of a plug-in card **550** of the invention containing an amplifier module **551** that is similar to amplifier module **120** of FIG. **2**. The amplifier module **551** includes a first amplifier stage **552**, a first phase filter **553** and a second amplifier stage **554**. The phase filter **553** is similar to the phase filter **100** of FIG. **1**.

FIG. **14** illustrates two plug-in cards **550** and **555**. In FIG. **14**, a second amplifier stage includes a first amplifier **554** and a second amplifier **557**, which are respectively and separately positioned on plug-in cards **550** and **555**. Plug-in cards **550** and **555** are arranged such that the output of first amplifier **554** is transmitted to the input of second amplifier **557**. Plug-in card **555** also includes a second phase filter **558** and a third amplifier stage **559**. Second phase filter **558** is similar to the phase filter **100** of FIG. **1**.

The invention has been disclosed with reference to specific preferred embodiments, to enable those skilled in the art to make and use the invention, and to describe the best mode contemplated for carrying out the invention. Those skilled in the art may modify or add to these embodiments or provide other embodiments without departing from the spirit of the invention. Thus, the scope of the invention is only limited by the following claims:

We claim:

1. An amplifier, comprising:

a first amplifier configured to receive a wideband input signal having a carrier signal and output a first amplified signal, the first amplifier introducing first CTB distortions of the carrier signal into the first amplified signal;

a first phase filter coupled to said first amplifier so as to receive said first amplified signal as an input, said first phase filter configured to output a first phase shifted signal;

a second amplifier coupled to said first phase filter so as to receive said first phase shifted signal and to output a second amplified signal, the second amplifier introducing second CTB distortions of the carrier signal; and

the first phase filter configured to shift a phase of the first amplified signal to an extent that substantially reduces accumulation of amplitudes of the CTB distortions produced by the first and second amplifiers while causing power of the CTB distortions produced by the first and second amplifiers to substantially accumulate.

2. The amplifier of claim **1**, further comprising:

a second phase filter coupled to said second amplifier so as to receive said second amplified signal as an input, said second phase filter configured to output a second phase shifted signal;

a third amplifier coupled to said second phase filter so as to receive said second phase shifted signal and to output a third amplified signal, the third amplifier introducing third CTB distortions; and

the first phase filter configured to shift a phase of the first amplified signal to an extent that substantially reduces accumulation of amplitudes of CTB distortions produced by the first, second, and third amplifiers while causing power of the CTB distortions produced by the first, second, and third amplifiers to substantially accumulate.

3. The amplifier of claim **2**, further comprising:

the first and second phase filters configured to shift a phase of the first amplified signal and the second amplified signal, respectively, to extents that substantially reduce accumulation of amplitudes of CTB distortions produced by the first, second, and third amplifiers while causing power of the CTB distortions produced by the first, second, and third amplifiers to substantially accumulate.

4. The amplifier of claim **1**, further comprising:

the phase shift of the first amplified signal between 15 and 60 degrees, and the phase shift of the second amplified signal between 15 and 60 degrees.

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